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The effect of mentally demanding cognitive tasks on rowing performance in young

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Abstract

Objectives: The present study aims to investigate the effect of mentally demanding cognitive tasks on rowing performance in prepubertal athletes. **Design:** Randomised, counterbalanced and crossover. **Method:** Seventeen rowers, aged between 10 and 12 years, completed three separate testing sessions during which they performed three different cognitive tasks before completing a 1500 m time trial on the rowing ergometer. In the two experimental conditions, one hour of a standard cognitive task (Stroop task) and an arithmetic school test were used to elicit mental effort; in the control condition a time-matched, not demanding activity was carried out (painting). Subjective workload and mood were measured before and after the treatments, and the motivation was recorded before the time-trial. During the time trial, time, power, speed, cadence, heart rate and rate of perceived exertion were assessed. **Results:** The Stroop task and the arithmetic test were rated more mentally demanding ($P < 0.001$), effortful ($P < 0.001$) and frustrating ($P = 0.001$) than the control task, but the items fatigue ($P = 0.437$, $P = 0.197$) and vigour ($P = 0.143$, $P = 1.000$) after the cognitive tasks were not significantly different from the control. The performance of the time trial did not differ between conditions (time: $P = 0.521$; power: $P = 0.208$; speed: $P = 0.341$); physiological ($P = 0.556$) and perceptual ($P = 0.864$) measures recorded during the physical task were not affected by the conditions. Accordingly, pacing profiles ($P = 0.312$) and cadence ($P = 0.062$) did not differ between the conditions. **Conclusions:** Mentally demanding activities did not affect the subsequent physical performance in prepubertal athletes.

Keywords: cognitive fatigue; endurance performance; young rowers; rpe

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Introduction

Acute mental fatigue is defined as a psychobiological state that may arise during or after prolonged cognitive activities and is characterized by the feelings of tiredness or even exhaustion, a decreased commitment and increased aversion to continue the current activity (Boksem, & Tops, 2008). It has been shown that acute mental fatigue has a detrimental effect on cognitive performance (Lorist, Boksem, & Ridderinkhof, 2005; Van der Linden, Frese, & Meijman 2003) and in other performance settings, such as driving (Craig, 2001) and physical performance (Van Cutsem et al., 2017).

Different studies reported that mental fatigue induced with prolonged cognitive tasks impaired the subsequent performance of constant load (Marcora, Staiano, & Mannning, 2009), self-paced (Brownsberger, Edwards, Crowther & Cottrell, 2013) and intermittent (Smith, Marcora, & Coutts, 2015) endurance tasks. These findings were replicated in different whole-body exercises, i.e. cycling (Martin et al., 2016) and running (MacMahon, Schücker, Hagemann, & Strauss, 2014; Pageaux, Lepers, Dietz, & Marcora, 2014). In addition, research reported impairment in the performance of local muscular exercise (Pageaux, Marcora, & Lepers, 2013) and isometric endurance handgrip (Bray, Martin Ginis, Hicks, & Woodgate, 2008; Grham & Bray, 2015) that followed demanding cognitive tasks. Recently, the detrimental carryover effect of mental fatigue has been extended to whole-body resistance exercises (Graham, Martin Ginis, & Bray, 2017; Head et al., 2016) and soccer-specific physical performance (Smith et al., 2016).

The studies associated the decline in the endurance performance with an increased rate of perceived exertion during exercise at constant load or a decreased workload/rate of perceived exertion ratio during self-paced exercise. On the contrary, the cognitive tasks did not affect the physiological variables commonly associated with endurance performance (i.e. heart rate,

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cardiac output, oxygen consumption) (see Van Cutsem et al., 2017). However, it still under debate whether mental exertion could alter the neuromuscular functions during the physical task that follows. In this regard, Bray et al. (2008) reported that muscular activation assessed with the EMG during an isometric submaximal contraction was increased after an ego-depletion task compared to the control condition. On the same line, Pageaux, Marcora, Rozand and Lepers (2015) found a higher EMG of the vastus lateralis during a whole-body cycling task following a mentally demanding task compared to the control condition. Conversely, it seems that mental exertion did not impair maximal muscular activation on a maximal strength task (Rozand, Pageaux, Marcora, Papaxanthis, & Lepers, 2014) nor affect the decline of maximal muscular activation induced by the endurance task (Pageaux et al., 2015). The last results indicated that the mental effort did not increase the development of central fatigue induced by physical exercise, though it may influence motor control (Pageaux et al., 2015).

Most of the studies mentioned above involved recreational or well-trained athletes. Interestingly, Martin et al. (2016) suggested that training history and performance level may interact with the effect of mental fatigue. Specifically, they compared the effect of mental fatigue on the following endurance performance in recreational and in elite cyclists. Their results showed that working for 30 min on a modified Stroop task diminished the performance in the recreational cyclist's group, while it did not affect the time trial of the elite athletes. Also, they reported that elite cyclists performed faster during the Stroop task then recreational, suggesting a potential association between resistance to mental fatigue and increased inhibitory control in professional cyclists. In accordance with that, it has been shown that faster ultra-endurance runners were better than the slower group in inhibiting the motor response (go-no go trials) and suppressing interference in a dual-task paradigm (Cona et al., 2015). These preliminary findings suggested that inhibitory control may be crucial for the success of the

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endurance athletes. However, it is unknown whether this characteristic is genetic or acquired through experiences.

Inhibitory control is part of the executive functions constituting the higher cognitive processes involved in the control of goal-directed behaviors, and it refers to the ability to overcome the preponderant response to guide behavior toward the task goal. Behavioral studies showed that although infants are able to suppress the more automatic response to generate appropriate task responses, the rate of inhibition improved across childhood until late adolescence. Hence, the neural mechanism underlined response inhibition are available early in the development, but the systems and the processes are less efficient and slower in children compared to adults (Luna, Padmanabham, & O'Hearn, 2010). Consequently, it is possible that children may exert further effort to perform the same task compared to adults. However, prolonged cognitive performance in children has received little attention and to our best knowledge, the only published article that evaluated the effect of mental fatigue in healthy children dated back to 1912 (Winch, 1912a, 1912b).

Throughout school days young athletes are engaged in mentally demanding activities such as classes, exams and homework that they alternate with training sessions and/or competitions. Therefore, it would be relevant for these athletes establishing the impact of activities that require mental effort on their physical performance. Furthermore, performance at school and adjusting training to school have been cited as potential factors leading to burnout among junior tennis player (Gould, Tuffey, Udry, & Loehr, 1996) and golfer (Cohn, 1990). Hence, the study of the relationship between acute mental fatigue and physical performance in young athletes could promote adequate strategies to monitor fatigue and foster a positive young athlete's development.

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Based on the results reported by Martin and colleagues (2016), investigations on the effect of mentally demanding tasks on the physical performance of prepubertal athletes could also provide additional information on when elite athletes' performance becomes less sensitive to prior mental effort offering future perspectives for talent identification and young athletes' development plans. Moreover, the interplay between mental and physical effort in children could also give an insight into the reciprocal effect of physical activity and cognitive performance.

Because of the large number of research attesting that mental fatigue impaired endurance performance in adults, the main aim of this exploratory study was to test whether this effect extended to the rowing performance of prepubertal children. At this age, the neural system and processes underlying inhibitory control are still immature. Hence, we hypothesised that working on demanding cognitive tasks known to elicit response inhibition would increase the feeling of fatigue and negatively affect the subsequent endurance performance compared to the control condition where a low demanding task was carried out.

The second aim of the study was to compare the effect of a standard computerised cognitive task as used by previous research (Van Cutsem et al., 2017) with everyday cognitive activities (i.e. homework, or exams) to assess whether the possible detrimental effect extended to more applied tasks.

Materials and Methods

Subjects

Eighteen young rowers (11 males and six females, 11 ± 1.06 year, 46.72 ± 11.14 kg, 154.79 ± 9.41 cm, > 2 training sessions per week, 1.5 ± 0.85 years of rowing experience) voluntarily participated in this study. All participants were recruited from a local rowing club affiliated to the Italian Rowing Federation. The required sample size was based on the effect of cognitive

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tasks on physical performance reported by previous studies using a within-subject design and a time trial as a physical task (Mac Mahon et al., 2014; Martin et al., 2016; Pageaux et al., 2014). The studies reported a large effect size, $\eta^2 p = 0.31$ to 0.683. The priori sample size calculation (G*Power version 3.1.9.2) with $F(v) = 0.73$, $\alpha = 0.05$, power = 0.80 indicated that a sample of 18 would be sufficient for the analysis. One subject did not meet the inclusion, and 17 subjects were included in the final analysis.

The athletes have regularly been involved in rowing training and competition for at least 6 months; during the three months preceding the data collection and throughout the period of the study subjects performed three to five training sessions per week of about 90 min, at least two of them were rowing-specific (on the rowing ergometer or outdoor) and one involved strength training. Eligibility criteria were as follows: aged 10 to 14 year, free from any known medical diseases, injuries, colour vision deficiencies and learning disorders, free from any medication. Parental consent was provided for all participants (subjects younger than 18 years), and procedures set by the university ethics committee for dealing with minors were followed. The study design and procedures were approved by the local research ethics committee of the University of Milan and followed the ethical principles for medical research involving human subjects set by the World Medical Association Declaration of Helsinki. Participants and their parents were not informed about the real aim of the study; however, they were provided with written instructions outlining all the procedures involved in the study.

Experimental design

A randomised counterbalanced cross-over design was used for the experimental component of the present study which involved three separate testing sessions. In two visits, they either performed one hr of a computerised cognitive task (Stroop task), or they worked on a customised standard school exam for the same duration. A third condition during which

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subjects performed a low demanding cognitive activity (painting Mandala) was used as a control. Physical performance was assessed with a 1500 m rowing ergometer time trial. The order of the experimental treatments (intervention 1; intervention 2; control) was randomly allocated based on uniformly balanced permutations (123/132/213/321/231/312) generated by a web-based computer program (www.randomization.com).

Experimental procedures

Subjects were tested individually on four different occasions. The visits were completed at the local gym where athletes used to train. The tests were performed within the training hours of the clubs when the access to the gym was limited to the athletes and their coach to maintain similar external conditions between the sessions. All procedures were carried out in an isolated room with standard environmental conditions (i.e. temperature: 18 ± 1 °C) located on the second floor of the structure where only the participant and the researchers could access. **Preliminary sessions.** During visit one, participants weight and height were measured, thereafter they were familiarised with the tests and measures to be used for the experimental sessions, i.e. Stroop task (for the time needed to reach a minimum of 90 % of accuracy), the psychological questionnaires and the physical task (subjects were asked to perform the whole-time trial).

Experimental sessions. The experimental visits lasted around 90 min and involved 60 min of either cognitive tasks or a control task (see section “Experimental treatments”) followed by the physical task. The sessions entailed the same procedures (Figure 1), other than the cognitive task employed (Stroop task, arithmetic test and control). Before and after each cognitive task mood was recorded with the Brunel Mood Scale (BRUMS). In addition, the subjective workload was measured at the end of the cognitive task with the NASA task load index (NASA-TLX) (see section “Psychological measurement”). Within 10 min after the completion of each

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respective experimental manipulation, subjects performed the physical task on the rowing ergometer. It involved 3 min of standardised warm-up followed by 1500 m of the time trial (see section “Physical task”). Motivation toward the physical task was assessed right before the starting of the warm-up (see section “Psychological measurement”).

The experimental visits were separated by seven days and performed on the same day of the week to maintain the mental workload prior to each test as similar as possible. Each participant carried out the visits individually and at the same time of day (within one hr period). Sessions starting times ranged from 14:00 to 18:00 among participants. Before each session, all participants received the instructions to sleep at least seven hours and to drink 35 $mL \cdot kg^{-1}$ of body weight within the 24 hours before the sessions. Moreover, they were required to refrain from homework or others cognitive activities and to avoid caffeine within the 2 hours before the visits and to eat a light meal one hour before the experimental sessions maintaining the meal consistent among the three visits. They were also asked to declare if they had taken any medications or had any injuries or illness. Full compliance with instructions was observed prior to testing sessions.

Experimental treatments

Intervention 1 – Stroop task

Participants performed a 60 min modified incongruent Stroop colour-word task. The Stroop task demands response inhibition and sustained attention (MacLeod, & MacDonald, 2000) and has been employed by previous research on the same topic (Pageaux et al., 2014; Smith et al. 2016). Four words (red, blue, green, and yellow) were randomly displayed one at a time on a computer screen. Participants were required to press one of four coloured buttons on the keyboard (red, blue, green, and yellow), with the correct response corresponding to the ink colour of the word (red, blue, green, and yellow), rather than the word’s meaning. Therefore,

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if the word *yellow* was written in blue ink, the correct response was *blue*. The words presented, and their ink colours were randomly generated and selected by computer software, E-Prime (Psychology Software Tools Inc., Pittsburgh, PA) and were 100 % incongruent. Words appeared centrally on a white background in 24-point uppercase Helvetica and lasted until subject gave a response. Subjects were instructed to respond as quickly and accurately as possible. Visual feedback was provided after each trial in the form of correct or incorrect response, reaction time and accuracy so far. Participants were familiarised with the Stroop task during the preliminary visit and performed 24 practice attempts prior to the experimental task to ensure they fully understood the instruction and to reduce the learning effect on performance. The total number of correct response for the entire 60 min Stroop task were calculated and the reaction time of the correct responses and accuracy (percentage of correct responses) were averaged for six blocks of 10 min during the 60 min Stroop task. In addition, the inverse efficiency score (IES) were calculated for the entire 60 min Stroop task The IES provides a measure for the speed/accuracy trade-off over time on task when accuracy is high (i.e. > 90% of correct responses). The index is computed by dividing the mean reaction time by the proportion of correct response: RT/ PC (Bruyer, & Brysbaert, 2011).

Intervention 2 - arithmetic test

Participants performed a 60 min customised arithmetic test. The task was a pencil-paper test involving arithmetic, mathematical and logic exercises taken from the national test, INVALSI, developed by Italian Ministry of Education (Istituto Nazionale per la Valutazione del Sistema Educativo di Istruzione e di Formazione). This test is employed as final grade assessment, and its questions cover the topics studied throughout the year. Seventeen different forms of the test were developed taking arithmetic, mathematical and logic questions from the general test. We provided different questions to each subject so that it was possible to adjust the test based on the individual age and grade and prevent answer suggestions among participants of the same

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grade. Every form involved blocks of 15 exercises. Blocks were structured similarly within each test and between every individual form and were given to the subject as soon as he completed the previous block. Participants were instructed to respond as accurately as possible to the questions and complete as many exercises as possible in 1 hr period. However, they were asked to leave an exercise blank, if they were not able to solve it. Research staff subsequently scored the test. The score was based on the number of correct responses given. This test was used to compare the fatigue induced by a typical school exam with that of a standard cognitive task. Arithmetic, mathematics and logic exercises were chosen as it has been suggested that mathematics skills rely on executive functions (Cragg, & Gilmore, 2014) and more specifically involve response inhibition (Gilmore, Keeble, Richardson, & Cragg, 2015).

Control condition

The control condition involved performing one hr of a not cognitively demanding task during which participants were asked to paint with a grey pencil to control for the effect of colours on arousal and performance (Elliot, & Maier, 2014). Participants were provided with a pre-drawn Mandala, and they were instructed to colour inside the spaces marked with black points. This task was selected because it has been suggested that colouring is a low cognitively demanding but engaging activity that did not entail envisioning and planning (Forkosh, & Drake, 2017). Participants were instructed to colour pre-selected part of the Mandala to reduce potential effect of creative processes on mood and affective state.

Physical task

A 1500 m time trial test on the rower-ergometer was used to meet the specific needs of the current investigation. Subjects were instructed to complete the time trial as fast as possible. All tests were performed on the same rowing ergometer (© Concept2 inc, Model D, Morrisville, VT) in the wind resistance mode (a spinning flywheel generates resistance). The distance was

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chosen to replicate the length of the national races for their age category and their training practice. Before starting the trial, they performed three min of standard self-pace warm-up during which they were instructed to maintain their perceived exertion between 2 and 3 of the 11-points CR10 scale developed by Borg (Borg, 1998). During the time trial, all participants received information about the distance covered at 500, 1000 and by the end of the test at 1250 m. However, they did not receive any feedback about their speed, cadence and heart rate (HR). No encouragements were provided throughout the trials. Participants reported their perceived exertion using the CR10 at every 150m interval. Moreover, HR was recorded throughout the whole tests (see section "Physiological measurements"). Power output and stroke rate were averaged for the warm-up and every 300 m of time trials. Furthermore, the average speed at every 150 m was calculated to assess the pacing strategy.

Psychological measurements

Rate of perceived exertion

The rate of perceived exertion (RPE) was registered in the last 15 s of the warm-up and every 150 m throughout the time trial with the 11-point CR10 developed by Borg (Borg, 1998). The CR 10 is a category–ratio scale that ranges from 0 (*no effort at all*) to 10 (*maximal effort ever experienced*) with a dot at the end to rate an effort that is higher than the one has ever been experienced. The subjects were asked to rate how heavy and strenuous the exercise felt by looking at the verbal expressions and then giving the number. Before the warm-up participants were given the standard instruction for the scale (Borg, 1998); for example, *3* on the scale is *moderate* it is not especially hard, it feels fine, and it is not a problem to continue exercising, *7* corresponds to *very hard* and strenuous exercise. A healthy person can still go on, but he or she really has to push him or herself. It feels very heavy, and the person is very tired. Also, they were reminded that *10* should correspond to the maximal exertion they have ever experienced

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in their past training or competitions and that the dot at the end should denote a perceived exertion stronger than *10*, the highest possible level of exertion (Borg, 1998). A copy of the scale was always in full view of the subject. This scale was chosen as the participants were already familiar with it and had been using it for at least three months during their daily training sessions prior to the tests taking place.

Mood

Mood was measured at the beginning of the visit and after the cognitive tasks with the BRUMS validated for adolescents (Terry, Lane, Lane, & Keohane, 1999). The questionnaire consists of 24 items divided into 6 subscales related to mood, Depression, Fatigue, Vigour, Confusion, Anger, Tension. Participants were asked to rate each item on a 5-point Likert scale (*from 0 = not at all, to 4 = extremely*) according to their current mood (*How do you feel right now?*). Each subscale score, with four relevant items, could range from 0 to 16. Fatigue and vigour were used as subjective markers of mental fatigue after cognitive tasks (Marcora et al., 2009).

Motivation

Motivation for the time trials was measured after the warm-up with a single item (*I am motivated to do the time trial*) on a 5-point Likert scale (*0 = not at all, 1 = a little bit, 2 = somewhat, 3 = very much, 4 = extremely*) (Martin et al., 2016).

NASA Training Load Index – subjective workload

The subjective workload was recorded after each intervention and after the physical test with the Italian version of the National Aeronautics and Space Administration Training Load Index (NASA-TLX) (Bracco, & Chiorri, 2006). It involves a multi-dimensional rating procedure with 6 domains (Mental demand, Physical demand, Temporal demand, Effort, Frustration). Subjects were asked to rate each of them on a 0 to 20 scale anchored by bipolar descriptors (high/low).

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Each score was multiplied per 5 so that the final score of each subscale would range from 0 to 100.

Before filling out the questionnaires, athletes were told that they should answer each question based on how they currently felt; there were no right or wrong answers, and they would not be judged on their answers.

Physiological measurements

During the cognitive tasks and the physical tests, HR was recorded with an HR monitor (Polar M400, © Polar Electro 2016, Oy, Kempele, Finland) and an HR band synchronised with the device. Ten min average and overall mean were used to analyse data of the cognitive task. Heart rate data were collected at every 150 m of the time trials.

Statistical Analysis

All data are presented as mean ± standard deviation (SD). Prior to the analysis, the Shapiro-Wilk's test and the Mauchly's test were employed to test the normality of the data and sphericity assumption respectively. When sphericity was not met, Greenhouse-Geisser correction was used to adjust the significance of the F-ratios. One-way repeated measures ANOVA was used to determine the differences between the three conditions in the time trials performance and in the average HR, power output, cadence and speed during the time trials, in the motivation toward the physical tests and in the subjective workload of the interventions (NASA-TLX). Two-way fully repeated measures ANOVA (3x2) was used to assess the effect of the interventions and time (pre and post interventions) on mood state (fatigue and vigour subscales of the BRUMS). Heart rate during the three interventions was averaged every 10 min and analysed with a two-way fully repeated measures ANOVA (3x6) to determine the effect of condition and time. One-way repeated measures ANOVA was used to assess the effect of time on task on the accuracy (% of correct trials) and reaction time during Stroop task. Two-

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way fully repeated measures ANOVA (3 x 10) was run to define the effect of the interventions and distance (every 150 mt) on the HR, RPE and speed during the trials and 2-way ANOVA (3 x 5) was run for cadence and power during the time trials (i.e. every 300 m distance).

In addition, a mixed 3 x3 ANOVA with the visits order listed as the between-subject factor and condition as the within-subjects factor was used to exclude a learning effect on the performance and bias in the ratings of the psychological questionnaires after the interventions.

Significant main effects and interactions, when more than two levels were employed, were interpreted through pairwise comparisons with Bonferroni correction. Significance was set at 0.05 (two-tailed) for all analyses, and the effect size for each statistical test is reported as partial eta squared (η^2p), using the small = 0.02, medium = 0.13 and large = 0.26 interpretation for effect size (Bakeman, 2005). Data analysis was conducted using the Statistical Package for the Social Sciences, version 23 (SPSS Inc., Chicago, IL, USA)

Results

Manipulation check

Average HR was lower during the Stroop task (85 ± 9 bpm) compared with the control condition (91 ± 10 bpm) (P = 0.038). However, it did not differ significantly between the arithmetic test (89 ± 11 bpm) and the other conditions (Stroop task: P = 0.209; Control: P = 1.000). Despite the significant main effect of time on the HR (F (5, 80) = 5.396, $P < 0.001$, η^2p = 0.265), the follow-up tests failed to reveal significant differences between the 5 min blocks. The analysis of the vigour and fatigue subscales of the BRUMS revealed a main effect of time (vigour: F (1,16) = 22, $P < 0.001$, η^2p = 0.580 and fatigue: F (1,16) = 20, $P < 0.001$, η^2p = 0.556). The fatigue increased over time and the vigour was lower after the interventions compared with baseline. Despite the significant interaction conditions X time (vigour: F (1.5, 25) = 4.107, P = 0.038, η^2p = 0.204; fatigue: F (2, 32) = 4.698, P = 0.016, η^2p = 0.227), the

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pairwise comparison of the ratings after the three interventions did not reach the statistical level for significance (vigour: control and Stroop task P = 0.143, control and arithmetic test P = 1.000, Stroop task and arithmetic test P = 0.164; fatigue: control and Stroop task P = 0.437 control and arithmetic test P = 0.197, Stroop task and arithmetic P = 0.100). The main effect of condition was not significant (vigour: F (1.5, 24) = 2.119, P = 0.151, η^2p = 0.117; fatigue: F (1, 20) = 2.821, P = 0.102, η^2p = 0.150) and the one-way ANOVA of the baseline values did not reveal significant differences among the three conditions, F (2, 32) = 1.908, P = 0.165 and F (2, 32) = 0.257, P = 0.775 for the vigour and fatigue respectively.

Thus, the level of fatigue as measured with the BRUMS did not show a significant effect of the two cognitive tasks. (Data presented in Table 1).

	Mood			
	Vigour		**Fatigue**	
	Pre	**Post**	**Pre**	**Post**
Stroop task	6.7 ± 3.8	4.1 ± 2.6	0.4 ± 1.1	2.5 ± 2.7
Arithmetic test	7.2 ± 3.3	5.1 ± 3.1	0.2 ± 0.4	0.9 ± 0.8
Control	6.2 ± 3.6	5.2 ± 3.4	0.4 ± 0.8	1.5 ± 1.6

Table 1. Mood for the three experimental conditions. Data are presented as mean ± SD.

On the other hand, the subjective workload assessed after the cognitive tasks using the NASA-TLX showed a main effect of condition for mental demand (F (2, 32) = 22.581, P < 0.001, η2p = 0.585), effort (F (2, 32) = 32.740, P < 0.001, η^2p = 0.672), temporal demand (F (2, 32) = 5.118, P = 0.012, η^2p = 0.242) and frustration (F (1, 21) = 8.911, P = 0.004, η^2p = 0.358). Pairwise comparisons revealed that mental demand (P < 0.001), effort (P < 0.001) and frustration (P = 0.001) were higher for both, the Stroop task and the arithmetic test, compared to the control condition, whereas the Stroop task and the arithmetic test conditions did not differ on these items (mental demand and frustration: P = 1.000, effort: P = 0.527). In addition, the temporal demand of the Stroop task was higher than the control task (P = 0.009); while the

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temporal demand of the arithmetic test did not differ significantly from the Stroop task (P = 0.922) and the control condition (P = 0.214). Physical demand and the performance did not differ between the three conditions (main effect of condition: F (1.5, 25.5) = 1.564, P = 0.229, η^2p = 0.089 and F (2, 32) = 1.956, P = 0.158, η^2p = 0.109). Data of subjective workload are reported in Figure 2.

The NASA-TLX scales of the time trial did not differ significantly between conditions, apart from the rating of performance that tended to be higher in the arithmetic test condition (performance: F (1.5, 23.5) = 3.847, P = 0.047, mental demand: F (1, 22) = 0.512, P = 0.538, physical demand: F (1, 21) = 0.452, P = 0.559, temporal demand: F (2, 32) = 0.299, P = 0.743, effort: F (2, 32) = 0.700, P = 0.504, and frustration F (2, 32) = 1.318, P = 0.282). The pairwise comparisons did not reveal significant differences between the performance scales (control and Stroop task P = 1.000, control and arithmetic test P = 0.198, Stroop task and arithmetic test P = 0.121).

Values of the motivation were 2.7 ±0.77, 2.35 ±0.86, 2.52 ±0.79 for the control condition, the Stroop task and the arithmetic test condition respectively. A non-parametric Friedman test was used to compare the values of three conditions and rendered a χ^2 (2) = 6.636 which was significant (P = 0.036). However, none of the pairwise comparisons conducted with Bonferroni correction reached the statistical level for significance (control and Stroop task P = 0.435; control and arithmetic test P = 1.000; Stroop task and arithmetic test P = 1.000).

The results of the mixed ANOVA for the order effect on the vigour and fatigue subscales were not statistical significant (between subjects effect for vigour F (5, 11) = 0.315, P = 0.894 and fatigue F (5, 11) = 0.678, P = 0.649 and interaction condition X order for vigour P = 0.786 and fatigue P = 0.676). Similarly, the order did not have a significant effect on the NASA-TLX items (mental demand: F (5, 11) = 1.078, P = 0.423 and F (10, 22) = 0.629, P = 0.773, temporal

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demand: F (5, 11) = 1.306, P = 0.330, F (10, 22) = 0.791, P = 0.638, effort: F (5, 11) = 0.850, P = 0.543, F (10, 22) = 0.386, P = 0.939 and frustration: F (5, 11) = 2.207, P = 0.127, F (7, 15) = 0.867, 0.551, respectively between subject effect and interaction condition X order).

Stroop task performance

Mean response time (RT) and accuracy (ACC) (percentage of correct responses) for the Stroop task were 794.7 ±127 ms and 0.98 ± 0.01 respectively. Repeated measures ANOVA was used to assess the effect of time on task on the behavioral responses averaged over 10 min period for a total of six blocks. RT tended to increase over time as it was also shown by a decrease in the number of trials performed over the six blocks. Specifically, RT was 759.49 ± 92.56 ms in the first block and 788.88 ± 104.08 ms in the last one. However, the effect of time did not reach the level of statistical significance (F (2, 38) = 2.410, P = 0.094, η^2p = 0.131). On the contrary, accuracy increased significantly with time (F (3, 48) = 6.799, P = 0.001, η^2p = 0.298). Post-hoc tests revealed that accuracy was significantly lower in the first 10 min (M = 0.96, SD = 0.02) compared with the third 10 min block (M = 0.977, SD = 0.01, P = 0.045) and the last 10 min block (M = 0.98, SD = 0.012, P = 0.006). The others comparisons with block 1 were not significant ($P \geq 0.09$), nor were significant the comparisons among all others blocks ($P \geq 0.9$) This trajectory suggested that after the first 10 min the accuracy stabilized and did not change for the remaining period.

Compatible with the trend of the RT, the IES increased slightly but, not significantly over the six blocks (F (2.5, 39.8) = 1.089, P = 0.357, η^2p = 0.064).

Arithmetic test performance

The total number of questions submitted during the arithmetic test was 75.88 ± 32.46. The number of correct answers was 38.38 ± 37.06, with a mean accuracy of 46.35 ± 24.83 %.

Effect of the interventions on time trial performance

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The mixed ANOVA to assess the effect of order on the time trial tests was not significant (between-subjects effect F (5, 11) = 0.316, P = 0.893, interaction condition X order (F (10, 22) = 0.931, P = 0.525). This result excluded a carryover effect of the three visits on the performance.

Times to complete the trials were 442.59 ± 63.97 s, 445.29 ± 61.52 s and 446.35 ± 62.30 s for the control condition, the Stroop task and the arithmetic test respectively (Figure 3). The performances were not significantly different (F (1.5, 26) = 0.604, P = 0.521, η^2p = 0.036).

Similarly, average power (F (2, 32) = 1.650, P = 0.208, η^2p = 0.093) and average speed (F (2, 32) = 1.111, P = 0.341, η^2p = 0.065) did not differ significantly and were 121.71 ± 50 W and 12.44 ± 1.76 $km{\cdot}h^{-1}$ after the control task, 118.94 ± 49.69 W and 12.35 ± 1.72 $km{\cdot}h^{-1}$ after the Stroop task and 118.92 ± 51.89 W and 12.33 ± 1.77 $km{\cdot}h^{-1}$ after the arithmetic test respectively. The velocity decreased over the trials (main effect of distance F (1, 21) = 105, P = 0.001, η^2p = 0.868). Post-hoc tests revealed that the speed declined significantly ($P \leq 0.002$) until 1050 m when it remained stable until the end (pairwise comparisons between the last four 150 m splits $P > 0.05$). The main effect of condition and the interaction condition X distance were not significant (F (2, 32) = 0.917, P = 0.410, η^2p = 0.054 and F (3, 51) = 1.049, P = 0.382, η^2p = 0.062 respectively).

Effect of the interventions on RPE, heart rate, pacing strategy and stroke rate during the time trials

RPE increased significantly over the trial (main effect of distance F (1, 22) = 57.637, $P < 0.001$, η^2p = 0.783), however, it was not affected by the interventions (main effect of condition F (2, 32) = 0.147, P = 0.864, η^2p = 0.009 and interaction condition X distance F (6, 102) = 0.929, P = 0.481, η^2p = 0.055). Post-hoc tests to describe the main effect of distance showed that the RPE increased significantly until 750 m ($P < 0.005$), it did not differ significantly between 750

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and 900 m (P = 0.086), 1050 and 1200 m (P = 0.163) and 1200 and 1350 m (P = 0.202) and it was significantly higher at 1500 m compared to all previous ratings (P < 0.05).

Similairly, the HR did not differ significantly between conditions (main effect of condition: F (2, 32) = 0.599, P = 0.556, η^2p = 0.038). It increased significantly over the trial (main effect of distance F (2, 31.5) = 79.66, P < 0.001, η^2p = 0.842) with no significant interaction condition X distance (F (6, 94.5) = 1.451, P = 0.201, η^2p = 0.088). Post-hoc tests for the main effect of distance showed that HR was significantly lower in the first 150 m split compared to the subsequent points (P < 0.001); in addition, it differ significantly between 300 (P $\leq$ 0.001) and 450 m ($P \leq 0.002$) and all splits following 750 m and between 600 m and all points following 900 m ($P \leq 0.02$) and at 1200 m, 1350 and 1500 m it was significantly higher compared to all previous recordings (P < 0.05).

One-way repeated measures ANOVA was run for the final point of RPE and the HR to assess whether the interventions influenced the end-point of the time-trial. However, the analysis did not reveal any significant difference between conditions in the RPE (P = 0.317, η^2p = 0.069) nor in the HR (P = 0.545, η^2p = 0.040). Data of RPE and HR over time are shown in Figure 4.

Average speed was obtained from each split times of every 150 m and used to assess pacing profiles of the trial. Before running the analysis to determine any difference between the conditions, a mixed ANOVA (with the order listed as the between-subjects factor) was performed to control the effect of the visits order on the pacing strategy. The results of the analysis were not significant (between-subject effect F (5, 11) = 0.369, P = 0.859, interactions condition X order F (10, 22) = 0.840, P = 0.597, and distance X order F (6, 14) = 0.770, P = 0.616).

Results from the 2-way fully repeated measures ANOVA showed a significant main effect of distance (F (4, 67.5) = 40.321, P < 0.001, η^2p = 0.716) on the average speed of every 150 m splits. The main effect of condition (F (2, 32) = 1.209, P = 0.312, η^2p = 0.070) and the interaction condition X distance were not significant (F (4.5, 72.4) = 1.484, P = 0.210, η^2p = 0.085). Post-hoc tests for the main effect of distance indicated that a reversed J pacing strategy was adopted in all the trials resulting in the first split being the fastest and in a significantly slower speed of all the following 150 m splits (P < 0.001). More specifically, the speed decreased significantly from split 2 to the following ones (P ≤ 0.03) until the last split when it increased to the same value of split 2 (P = 1.000). In addition, it was significantly higher in the 4th split (600 m) compared to the 6th, 7th and 8th (900 to 1200 m) and in the last split compared to the 7th, 8th and 9th (1050 to 1350 m) (Figure 5).

Average stroke rate was 28.65 ±3.33, 27.94 ±2.97, 28.88 ±3.28 rpm for the control, Stroop task and arithmetic test condition respectively. The main effect of condition (F (2, 32) = 3.038, P = 0.062, η^2p = 0.160) and the interaction condition X distance (F (4, 61) = 0.385, P = 0.811, η^2p = 0.024) were not significant. Post-hoc tests for the main effect of distance (F (1.6, 25.6) = 8.446, P = 0.003, η^2p = 0.345) showed that the stroke rate was higher in the first 300 m split compared to the three subsequent splits (P < 0.001, P = 0.006, P = 0.017) and increased to the same level of the first split in the last 300 m (P = 1.000), at this point was also significantly higher than the previous 300 m split (P = 0.024).

In the arithmetic test condition, the average stroke rate tended to be higher compared to the Stroop task condition. However, one-way repeated measures ANOVA of the average stroke rate was not significant (F (2, 32) = 2.728, P = 0.081, η^2p = 0.146).

Discussion

To our knowledge, this was the first study investigating the effect of mental fatigue on physical performance in a sample of prepubertal athletes. A recent review of the effect of mental fatigue on physical performance reported that acute mental fatigue before exercise performance could negatively affect endurance performance (Van Cutsem et al., 2017). In contrast, the main

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finding of the present study was that prolonged cognitive activities did not affect rowing performance in prepuberal athletes. Accordingly, physiological and perceptual responses during the time trials were not different after the three interventions (Stroop task, arithmetic test and control task).

Self-reported measures were recorded before and after the interventions to assess the state of mental fatigue. From one side, the mood state was similarly affected by the three interventions that resulted in a significant decrease in the vigour and significant increase in the fatigue. Thus, the measures from the BRUMS scale suggested that the two cognitive tasks failed to elicit a significantly different level of fatigue compared to the control activity.

On the other hand, the two cognitive tasks were rated as more mentally demanding, more effortful and more frustrating compared to the control task in the NASA-TLX.

Although these results were divergent in defining whether mental fatigue was effectively induced, similar findings were reported by previous studies (Pageaux et al., 2014; Pageaux et al., 2015). In both studies, the authors employed a modified version of the Stroop task to induce mental fatigue and a congruent version of the same task as a control. None of the two tasks affected the fatigue scale of the BRUMS, while the vigour score decreased similarly after the interventions. However, the ratings of mental demand and effort were significantly higher in the NASA-TLX of the incongruent Stroop task compared to the congruent version and most importantly, the physical performance was impaired after the more effortful and demanding task. Specifically, in the first study, the distance covered during the time trial was significantly shorter following the demanding cognitive task compared to the control (Pageaux et al., 2014); in the second study, the rate of perceived exertion measured during six min of constant load test was significantly higher in the incongruent Stroop condition (Pageaux et al., 2015). Their findings suggested that the physical performance may be more sensitive to the subjective experience of effort and/or the perceived demand of the previous cognitive task rather than the state of fatigue assessed with the BRUMS. Martin et al. (2016) also reported similar findings showing that a different fatigue state did not accompany the reduction in the endurance performance found after the Stroop task when compared to a passive activity. In particular, the fatigue level measured with the four-dimensional mood scale displayed a significant increase in tiredness and a significant reduction in positive energy in both conditions. However, the mental demand and the effort rated on the NASA-TLX were significantly higher after the Stroop.

Based on that, it could be argued that the lack of an effect of the more effortful cognitive tasks in the present study depended at least in part on the fact that the sample tested was different for age or training status to that of previous research.

To our knowledge, only one other study directly investigated the effect of mental fatigue in healthy children (Winch 1912a, 1912b). The author looked at the effect of a school day on a memory test performed either in the afternoon or the morning in both 11 and 13 years children. Winch (1912a, 1912b) reported little differences between the performance of the two groups as well as in the learning effect tested as the improvement in the performance from the preliminary test to the final test. Specifically, in the first experiment involving 45 children aged 13 years old, the average marks were 266 ±34 and 253 ±35.9 (out of 360) for the morning group and afternoon group respectively. In the second experiment, which included 61 boys of 11 years old, the morning group scored 165 ±1.1 and the afternoon group 161 ±1.1 out of 180. The same author suggested that children may be immune to mental fatigue and may be able to learn in the afternoon in the same way as in the morning.

The present results showed that the physical performance of young athletes was less sensitive to mentally demanding tasks compared with that of adult recreational athletes whose performance have been shown to decline after prolonged cognitive tasks (Van Cutseme et al., 2017). Hence, it is possible that the children tested were more resistant to mental fatigue because of the age, the training background and fitness level or both.

In the first case, these findings could be explained by the differences in the cognitive processes between adults and children. Behavioral and neuroimaging studies reported that brain areas underlying response inhibition, the frontal lobe, developed between 12 to 17 years and peak around 17 years (Romine, & Reynolds 2005). Over this period, functional neural networks develop and task-specific patterns of activation supporting the cognitive performance increase (Adleman et al., 2002; Rubia, Smith, & Woolley, 2006). Specifically, Adleman et al., (2002) reported increased performance activation of the lateral prefrontal lobe, anterior cingulate and parietal brain regions in young adults compared to children when performing the Stroop task. The decreased activity in the immature systems of children could be interpreted as reduced accessibility to the regions or to the computational abilities that support complex behavior (Luna et al., 2010). This lower activation during cognitive tasks may result in a lower impairment of the cognitive processes when activated over time, similarly to what occurs with exercise-induced peripheral fatigue (Ratel, 2006). The author suggested that children despite being physically less efficient compared to adults, i.e. lower maximal power and maximal aerobic capacity (maximal oxygen consumption), display less muscular fatigability because their muscular activation is quantitatively and qualitatively different. In particular, their underdeveloped anaerobic metabolism and the reduced recruitment of fast twitches result in lower accumulation of muscle by-product during high-intensity exercise and higher resistance to muscular fatigue (Ratel, 2006).

Similarly, it could be speculated that the reduced ability to recruit the neural resources during cognitive tasks in the children (Luna et al., 2010) may prevent their full exploitation and result in reduced fatigability over time, although it leads to a worse performance compared with that of adults. However, we are not aware of any study that compared the fatigability of the neural systems in children and adults or investigated the different effect of mental fatigue between adults and children; therefore, further empirical studies are necessary to test this possibility.

A more plausible explanation for the lack of the effect of mental fatigue on the performance could be the involvement of the children in endurance sport. In accordance with that, Martin et al. (2016) found that elite athletes' performance was not affected by previous mental fatigue and they suggested that elite cyclists could be more resistant to mental fatigue. Our results partly supported this hypothesis suggesting that endurance athletes displayed this characteristic at an early age.

Although they suggested that genetic factors likely support this feature, also the engagement in aerobic exercise and training routine may promote the development of resistance to mental fatigue in endurance athletes.

A growing body of evidence suggested that aerobic fitness (Buck, Hillmann, & Castelli, 2008; Scudder et al., 2014) and level of physical activity (Syväoja, Tammelin, Ahonen, Kankaanpää, & Kantomaa, 2014) are positively associated with the cognitive performance across different executive functions in prepubertal children (see Donnelly et al., 2016 for a review on this topic). These behavioral findings have been corroborated by studies involving the measures of brain structure (Chaddock, Erickson, Prakash, Kim et al., 2010; Chaddock, Erickson, Prakash, VanPatter et al., 2010) and function (Hillman, Buck, Themanson, Pontifex, & Castelli 2009; Hillman, Castelli, & Buck, 2005; Pontifex et al., 2011). Specifically, Chaddock et al. (2010) showed in two separate studies that children with higher fitness level outperformed their lower fitness peers in a relational memory task and resulted less susceptible to the behavioral interference measured with the Flanker task. The two behavioral outcomes were coupled with a larger volume in the brain structures underlying tasks' performance, namely the hippocampus and the dorsal striatum (nucleus caudate and putamen) for the relational memory and interference control respectively. These results suggested that the relationship between fitness level and cognitive performance may be mediated by direct and selective differences in the brain structure and volume. Studies assessing brain function with electroencephalogram have confirmed the presence of fitness related differences in the cognitive processes sustaining the performance. Specifically, a series of studies reported that children with high fitness level presented larger P3 amplitude signalling greater allocation of attentional resources during stimulus encoding compared to peers with lower fitness level (Hillman et al., 2009, Hillman et al., 2005; Pontifex et al., 2011). In addition to that, the high fitness level group displayed reduced ERN amplitude (event-related negativity) that was interpreted as an increased evaluative threshold to initiate top-down cognitive control as well as greater ERN differences between compatible and incompatible trials that was related to a better ability to modulate cognitive control in response to the stimuli (Pontifex et al., 2011).

Further support to the positive effect of exercise on cognitive performance has been provided by empirical studies showing that acute exercise facilitated cognitive performance in preadolescent children (Hillman et al., 2009; Chen, Yan, Pan, & Chang 2014).

Altogether, these results indicate that aerobic exercise involves specific cognitive processes that have a potentially positive effect on higher-order brain regions and support the development of cognitive functions across childhood and adolescence. Due to the positive interplay between cognitive functions and aerobic activities young and well-trained endurance athletes may need a low level of effort to sustain prolonged cognitive activities, and this may have reduced the effect of the interventions used to elicit mental fatigue.

In addition, physical activity during school hours is not detrimental to the performance at school (Ahamed et al., 2006) and its benefit may translate into improvement in academic performance (Marques, Santos, Hillman, & Sardinha, 2017), suggesting that children could adapt positively to the alternation between cognitive demand imposed by school routine and physical demand of structured sport. Based on that, the athletes of the present study could have been well adapted to shift from cognitive and physical activities. Therefore their performance was less sensitive to the intervention. Notably, all but three of them have been involved in rowing for at least one year before starting the experiment and they all have a history of at least four consecutive years of routinely sports practice prior to rowing.

Finally, it could be suggested that endurance athletes are predisposed or trained to endure effort in general. In this regard, fatigue has been defined as an evolutionary emotion that manifests with an increased feeling of effort and is driven by a cost-benefit analysis of the current activity (Boksem & Tops, 2008). The phenomenology of effort would allow disengaging from the task when the cost of acting overcome task reward and this monitoring system would favour efficient goal-directed behavior (Hockey, 2011; Kurzban, 2016). Accordingly, it was shown that increasing the reward during prolonged cognitive task counteracted the detrimental effect of mental fatigue on the cognitive performance and reversed the subjective feeling of effort and aversion to the task (Hopstaken, van der Linden, Bakker & Kompier 2015; Hopstaken, van der Linden, Bakker, Kompier, & Leung 2016). Boksem, & Tops (2008) suggested the presence of a shared neural system that evaluates and regulates mental and physical effort (see also Shenhav et al. 2017) and the detrimental carryover effect of mental fatigue on following physical tasks provided support to this hypothesis. Although research has failed to reveal a reduction in the motivation toward the physical endurance task that followed the cognitive tasks (Van Cutsem et al., 2017), studies consistently reported an alteration in the rate of perceived exertion during the exercise. The higher perceived exertion during exercise could imply an imbalance in the reward-effort processing elicited by the previous mental effort. Also, Brown & Bray, (2017) recently found that monetary incentives associated with the performance could offset the adverse effect of a short cognitive task on the performance of the subsequent handgrip endurance test, showing that task reward could affect the relationship between mental fatigue and physical performance. Inzlicht Shenhav, & Olivola (2018) suggested that *effort*, although commonly considered as inherently costly, could also add value to an activity or be a value itself through learned industriousness or need for cognition. Consequently, it could be argued that the young athletes tested in the present study, as well as the elite sample tested by Martin et al. (2016), may perceive the physical task as rewarding per se because its conditioned association with incentives (success, money) and/or individual predisposition to engage in effortful activity. According to the opportunity-cost model of mental effort (Kurzban, Duckworth, Kable, & Myers, 2013), this intrinsic value of physical exertion would result in little or no effect of the previous mental exertion on the performance of these athletes.

Though, these are speculations that require empirical evidence. Future studies should compare the effect of mentally demanding task on the performance of aerobic-trained children and sedentary peers, and a neurophysiological and psychological assessment should be implemented to test these hypotheses. Research on this topic should also explore potential psychological variables that mediate or influence the effect of mental fatigue on performance to improve the understanding of this phenomenon and to better interpret the results.

For example, task self-efficacy was shown to mediate the effect of self-control on the following physical performance through a sequentially mediated pathway, that was self-control tasks induced fatigue that affected task self-efficacy and, ultimately the performance on the second task (Graham, & Bray, 2015; Graham, Martin Ginis, & Bray, 2017). So far, no studies have investigated task self-efficacy as a mediator of fatigue-performance relationship in young athletes as well as in professional athletes. Hence future investigations should include this measure to assess whether they may be more resilient to the decline in self-efficacy induced with mental fatigue.

Similarly, Voce & Moston, (2015) and Wan & Stherntal, (2008) reported that performance feedback that allowed to monitor the performance level objectively could vanish the effect of ego-depletion on the subsequent cognitive performance. Performance feedback could represent a possible avenue for future research on mental fatigue and physical performance. In particular, it may be that with the practice athletes become able to better monitor the performance with their subjective feelings even in the absence of external feedback.

In conclusion, the present findings favour the hypothesis that *resistance to mental fatigue* could be a distinctive characteristic of endurance athletes and it develops at an early age (Martin et al., 2016).

Furthermore, this study showed that children endurance performance was not affected by performing a more complex cognitive task involving reasoning, decision-making and planning compared with the Stroop task.

Despite the new insight into mental efforts in trained children, the study presented some methodological limitations that should be acknowledged when interpreting the results.

Firstly, as stated above self-reported measures did not clearly distinguish the level of mental fatigue induced by the interventions. Different scales have been employed to assess the subjective state of fatigue with contradictory findings (Van Cutsem et al., 2017); however, a direct comparison of these assessments and a gold standard measure of the subjective feeling of fatigue is still lacking. A multidimensional assessment comprising different neurophysiological measures (i.e. electroencephalogram) and a secondary cognitive task may be necessary to gauge the cognitive and physiological effects of the cognitive task and elucidate the relationship between mental exertion and physical performance (Van Cutsem et al. 2017). In this regard, the present investigation did not include relevant psychological variables that were shown to mediate the effect of mental fatigue on physical performance such as task-self efficacy (Graham, & Bray, 2015; Graham, Martin Ginis, & Bray, 2017).

A second element requiring further attention is the type of cognitive tasks employed to induce mental fatigue. In the current study, the Stroop task was 100% incongruent, namely colour-words and ink-colour did not match in any trial. The incongruent trials of the Stroop task require higher cognitive control than the congruent trials as they elicit the inhibition of the automatic response to the colour-word (Botvinick et al., 2001). It has been reported that the response inhibition required by the incongruent Stroop task could have a negative effect on the subsequent physical performance (Englert & Wolff, 2015; Graham & Bray 2015; Martin et al., 2016; Pageaux et al., 2014). Moreover, Brown and Bray (2017) demonstrated that this effect could be elicited for tasks as short as 6 min and persisted up to 10 min of task duration.

However, it was shown that when the incongruent stimuli were presented at a high rate, the interference effect diminished (Lindsay, & Jacoby, 1994). As a consequence, the repetition of the incongruent stimuli over one hr period could reduce the interference and strengthen the colour-naming response. This could have led to more automatic responses reducing the effort required to sustain the task and ultimately, the effectiveness of the intervention. Future studies should assess the effect of different types and the lengths of the cognitive tasks on the subsequent performances. In addition to that, the manipulation of the second effortful task could also be relevant from a theoretical perspective to entangle the research on self-control and mental fatigue and their effect on physical performance.

The experimental sessions were performed on school days from 14:00 to 18:00. Therefore, it could not be excluded that the detrimental effect of mental fatigue on physical performance had already been exacerbated by other activities limiting the effect of the cognitive tasks. However, it should be noted that children were asked to abstain from any cognitive activity for at least two hours before starting the experimental sessions and the fatigue scale of the BRUMS did not display any level of fatigue in the baseline assessment. Future studies should test the same protocol during weekends to exclude the presence of a floor effect on the physical performance.

In the present study, we implemented a cross-over design where the visits were randomly allocated to the subjects based on balanced permutations, yet a Williams design would be more appropriate to control for the carryover effects.

The above limitations highlighted relevant issues for the research in the field of mental fatigue and physical performance that should be addressed by future research.

Conclusions

Several studies reported that mental fatigue has a detrimental effect on endurance performance in healthy recreational athletes (Van Cutsem et al., 2017). The current study is the first investigating its effect in trained children performance and provides preliminary experimental evidence that mental effort, elicited with a Stroop task or an arithmetic test, does not limit the following exercise performance in prepubertal endurance athletes. However, it should be noted that self-reports of fatigue did not differ between conditions, limiting our ability to determine the extent to which fatigue was induced by the more mentally demanding cognitive tasks. Therefore, its finding needs to be replicated by further researches implementing a broader psychophysiological assessment of mental fatigue.

Future research should investigate whether this effect depends on the age or the involvement in endurance activities comparing the response in sedentary and active children as well as across developmental years. Health interventions in paediatric settings, physical education programs as well as young athlete's development framework could take advantage from the investigation of the perceptual and functional consequences of prolonged periods of demanding cognitive activity and its interplay with physical fatigue during the development. The study of the interplay between cognitive functions and endurance performance in young athletes could help improve talent identification programs and young athlete's development programs.

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Figure captions

Figure 1. Schematic of the experimental visits. HR – Heart Rate; RPE – Rate of Perceived Exertion; ST – Stroop Task; AT – Arithmetic Test; CON – Control.

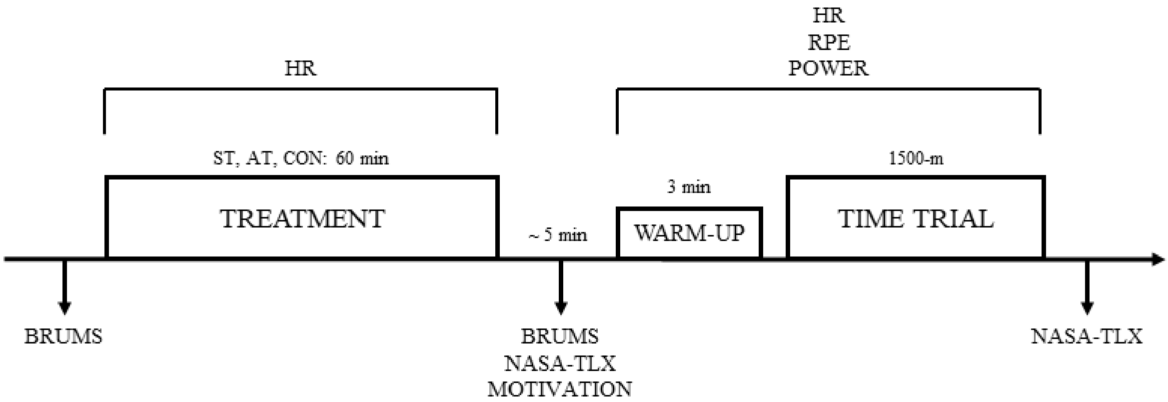

Figure 2. Effect of prior cognitive tasks (CT) on subjective workload measured with NASA-TLX scale. **Significant main effect of condition (P<0.01). ***Significant main effect of condition (P < 0.001). Data are presented as mean ± SD.

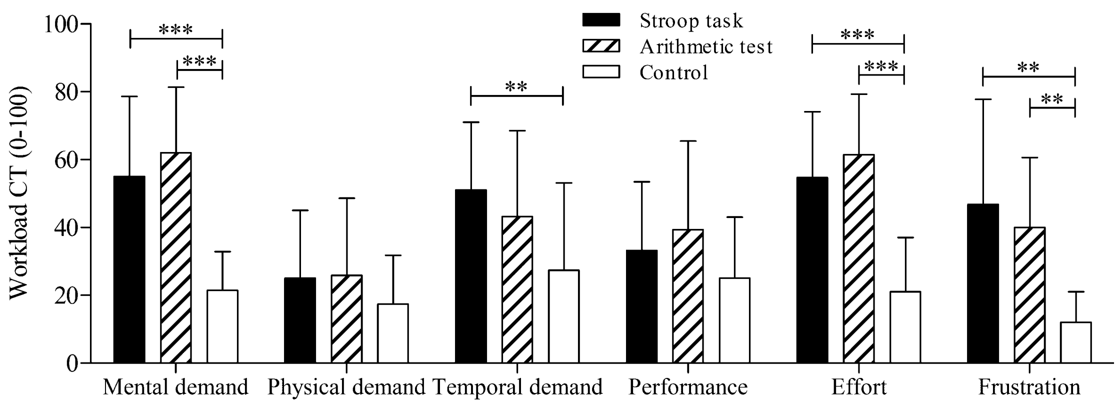

Figure 3. Effect of prior cognitive tasks on 1500-m time trial performance. Data are presented as mean ± SD (left) and individual responses (right).

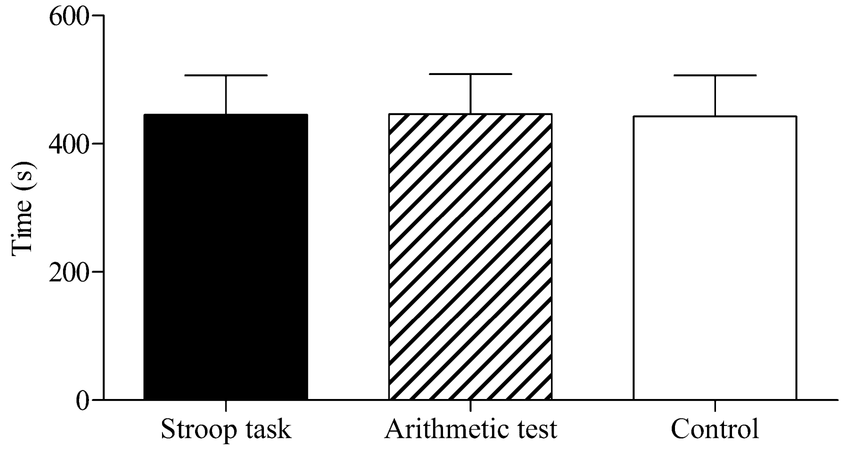

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Figure 4. Effect of prior cognitive tasks on rating of perceived exertion (RPE; A) and heart rate (HR; B) during the 1500-m time trial. ### Significant main effects of time (*P* < 0.001). Data are presented as mean ± SD.

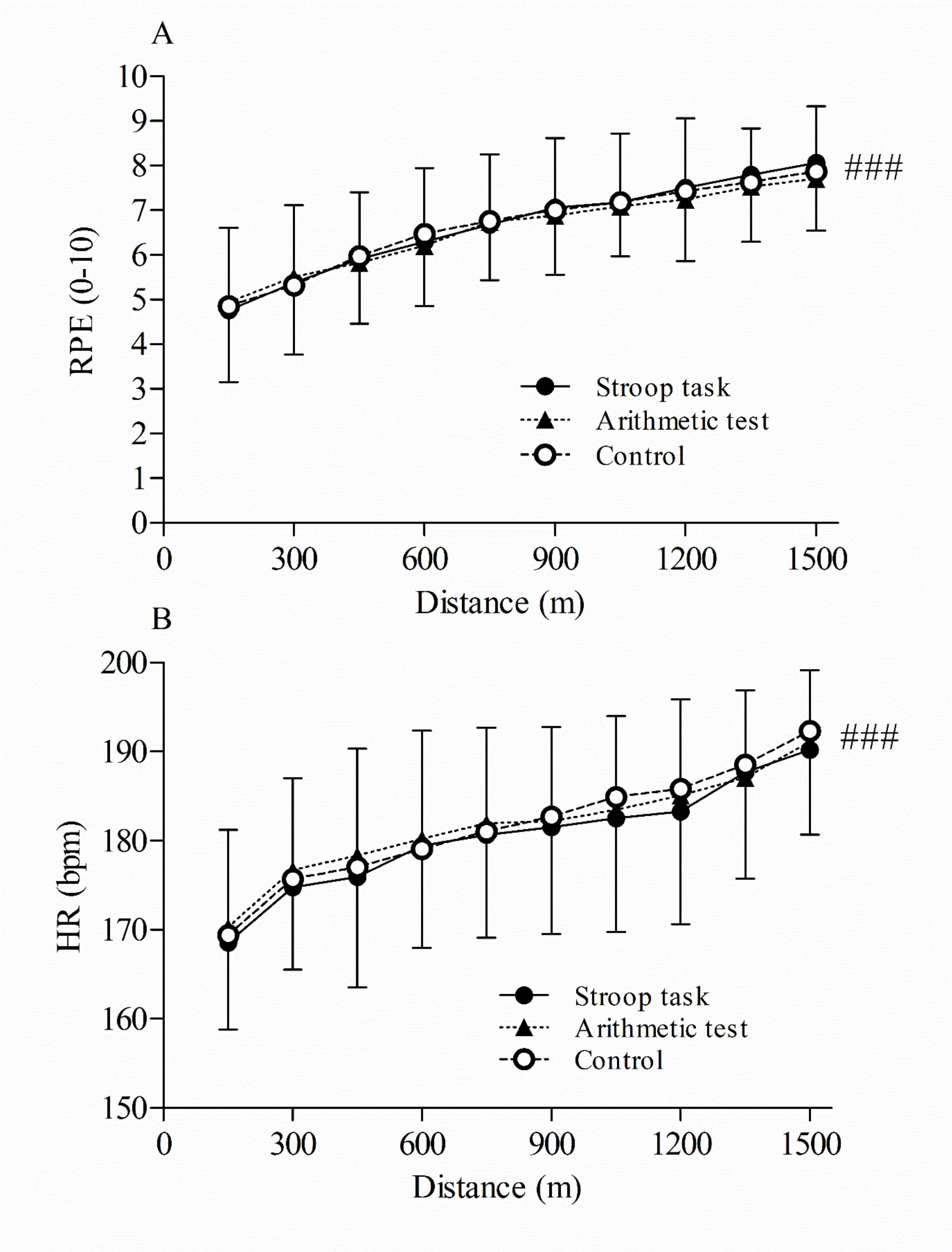
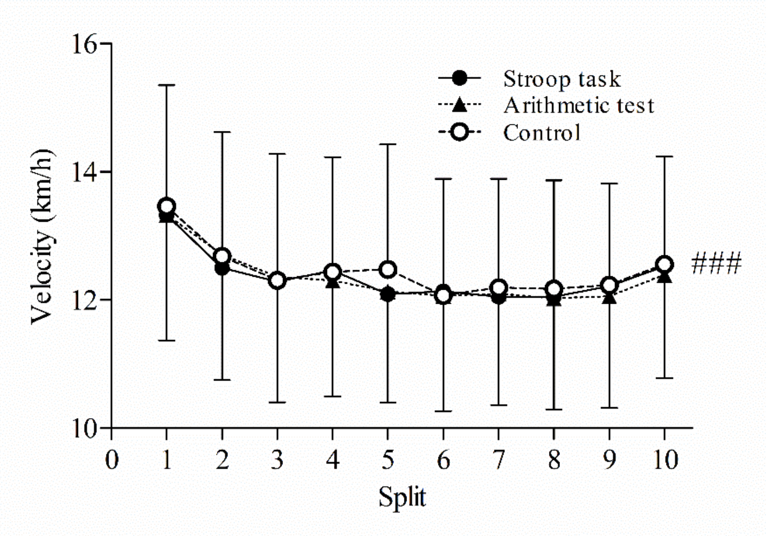


Figure 5. Effect of prior cognitive tasks on pacing strategy during the 1500-m time trial.

Significant main effects of time (P < 0.001). Data are presented as mean ± SD



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